Queen's University Belfast

Compton Scattering and Radiation Reaction Studies

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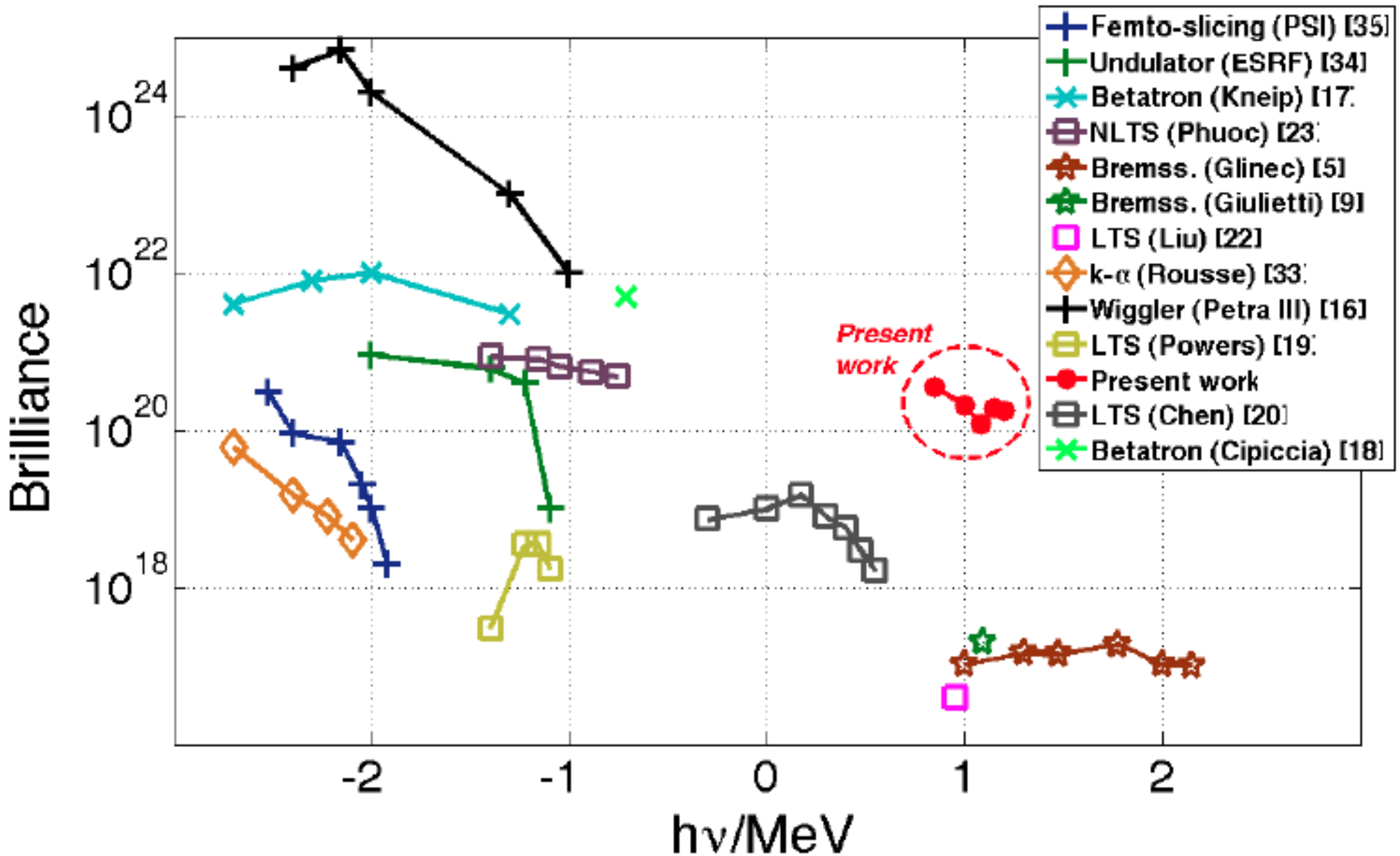
Talk Outline

- **RATIONALE**
  - Next generation of multi-MeV γ-rays from PW interactions
  - Quantum and Classical Radiation Reaction
  - Photon-photon scattering cross-section
- **THEORETICAL PREDICTIONS**
  - Next generation of multi-MeV γ-rays
  - Quantum and Classical Radiation Reaction
  - Photon-photon scattering cross-section
- **GENERAL EXPERIMENTAL SETUP**
- **EXPERIMENTAL TECHNIQUES**
  - fs-scale synchronisation
  - γ-ray spectrometer
  - Pixelated scintillators
  - Double magnetic spectrometer
- **CONCLUSIONS**

Rationale

- **NEXT GENERATION OF MULTI-MEV γ-RAYS**



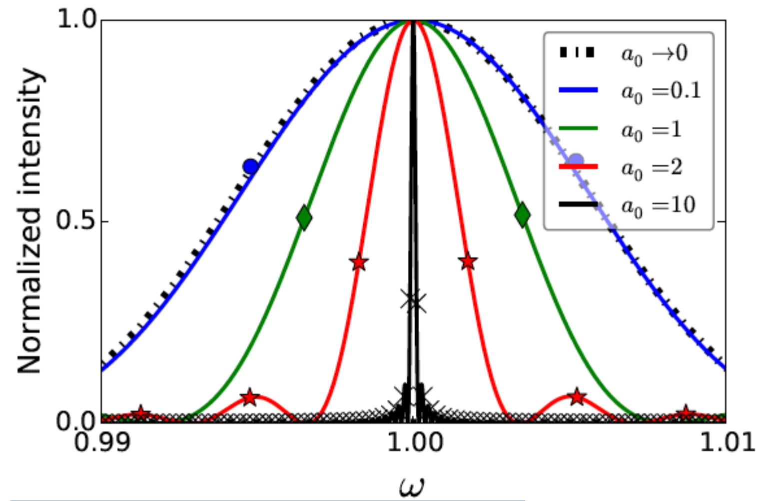
Rationale

- **MONOCHROMATIC γ-RAYS FROM NON-LINEAR COMPTON SCATTERING**

- Photon energy: $$\hbar\omega_X \sim \frac{4\gamma_e^2 \hbar\omega_L N_{ABS}}{1+(\gamma_e\theta)^2+\frac{a_0^2}{2}+2\frac{N_{ABS}\chi}{a_0}}$$

- Photon number: $$\begin{cases} N_X \sim 1.5\times10^{-2} a_0^2 & for \quad a_0 << 1 \\ N_X \sim 3.38\times10^{-2} a_0 & for \quad a_0 \geq 1 \end{cases}$$

- Bandwidth: $$\frac{\Delta\omega_X}{\omega_X} \sim \sqrt{\left(\frac{a_0^2}{2}\right)^2+\left(\frac{\Delta\omega_L}{\omega_L}\right)^2+\left(\frac{2\Delta\gamma_e}{\gamma_e}\right)^2}$$



S. Rykovanv et al. ArXiv (2014)

INPUT

Electron energy ~ 1 GeV
Electron bandwidth ~ 10%
Electron number ~ 10^9
Laser dimensionless intensity ~10
Chirped laser pulse

OUTPUT

Photon energy > 100 MeV
Photon pulse duration ~ 10s fs
Photon number ~ 4×10^8
Photon divergence ~ 5mrad
Bandwidth ~ 20%
Brilliance: $>10^{21}$ ph s^{-1} mm^{-2} $mrad^{-2}$ x0.1%BW

Rationale

▪ MONOCHROMATIC γ-RAYS FROM NON-LINEAR COMPTON SCATTERING

- Photon energy: $$\hbar\omega_X \sim \frac{4\gamma_e^2 \hbar\omega_L N_{ABS}}{1+(\gamma_e\theta)^2 + \frac{a_0^2}{2} + 2\frac{N_{ABS}\chi}{a_0}}$$
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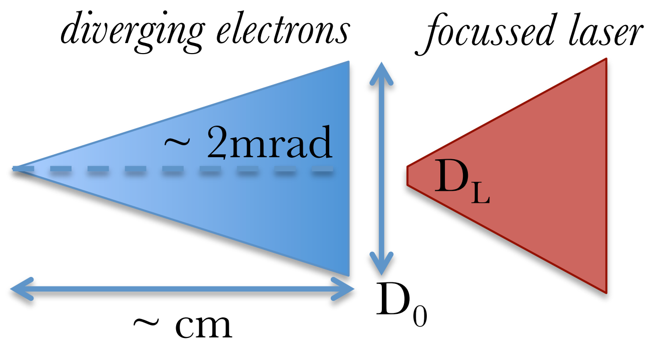


$D_0 \sim 70$ µm
$D_L \sim 3$ µm ➔ $N_{int} \sim \left(\frac{D_L}{D_0}\right)^2 N_e \sim 2\times10^{-3} N_e$

INPUT

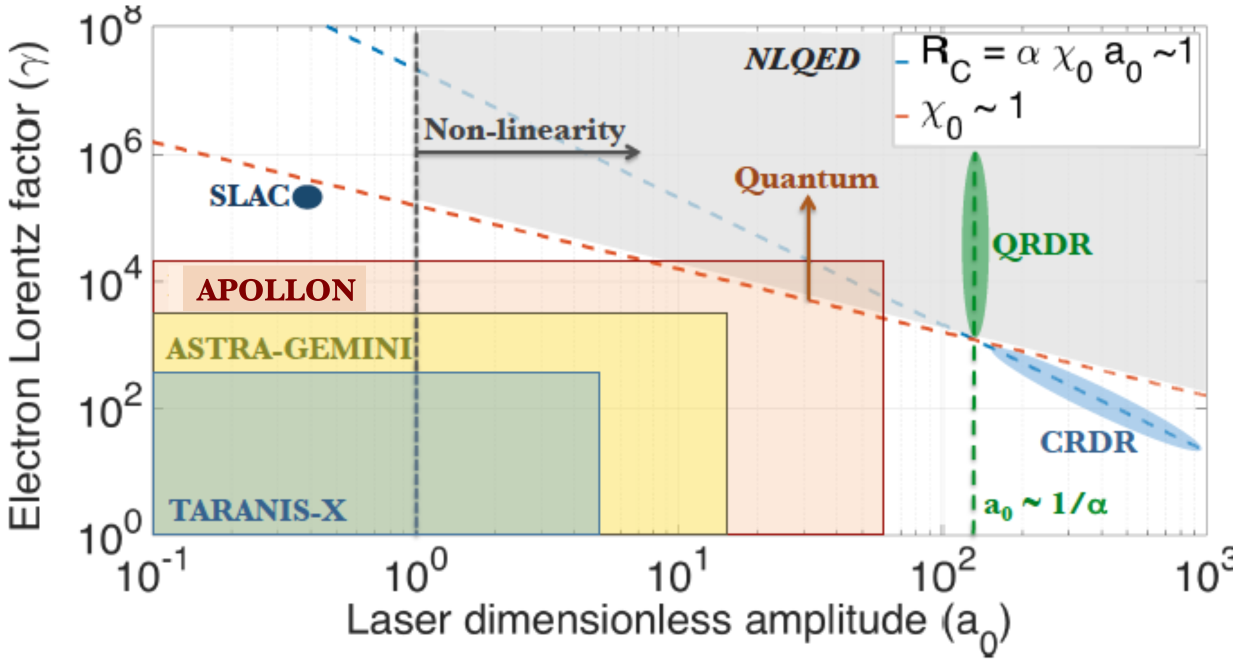
Electron energy ~ 0.6 GeV
Electron bandwidth ~ 10%
Electron number ~ 10^9
Laser focal spot ~ 70 µm
Laser dimensionless intensity ~ 6
Chirped laser pulse

OUTPUT

Photon energy ~ 60 MeV
Photon pulse duration ~ 10s fs
Photon number ~ 2×10^8
Photon divergence ~ 3.6mrad
Bandwidth ~ 20%
Brilliance: ~10^{21} ph s^{-1} mm^{-2} mrad^{-2} x0.1%BW

Rationale

- **RADIATION REACTION STUDIES**

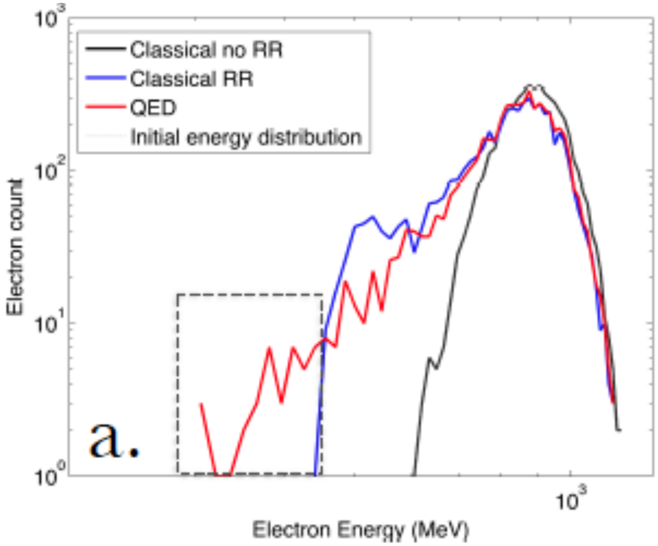


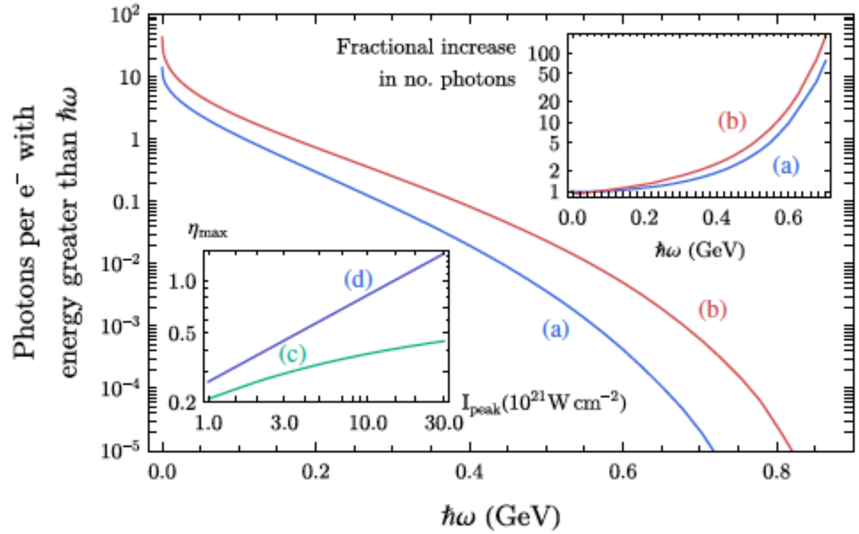
- *non-linearity* ($a_0 > 1$) equivalent to multi-photon absorption
- *quantum effects* ($\chi \sim 1$) significant electron recoil and pair production
- *CRDR* electron converting all its energy in photons in a laser period
- *QRDR* multiple photon emission in one laser period

Possibility to access electrodynamics beyond the LL approximation of interest for particle acceleration and astrophysics

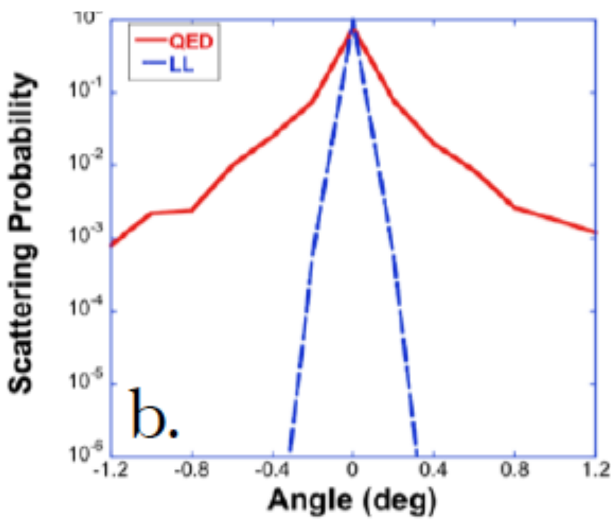
Rationale

- **RADIATION REACTION STUDIES**



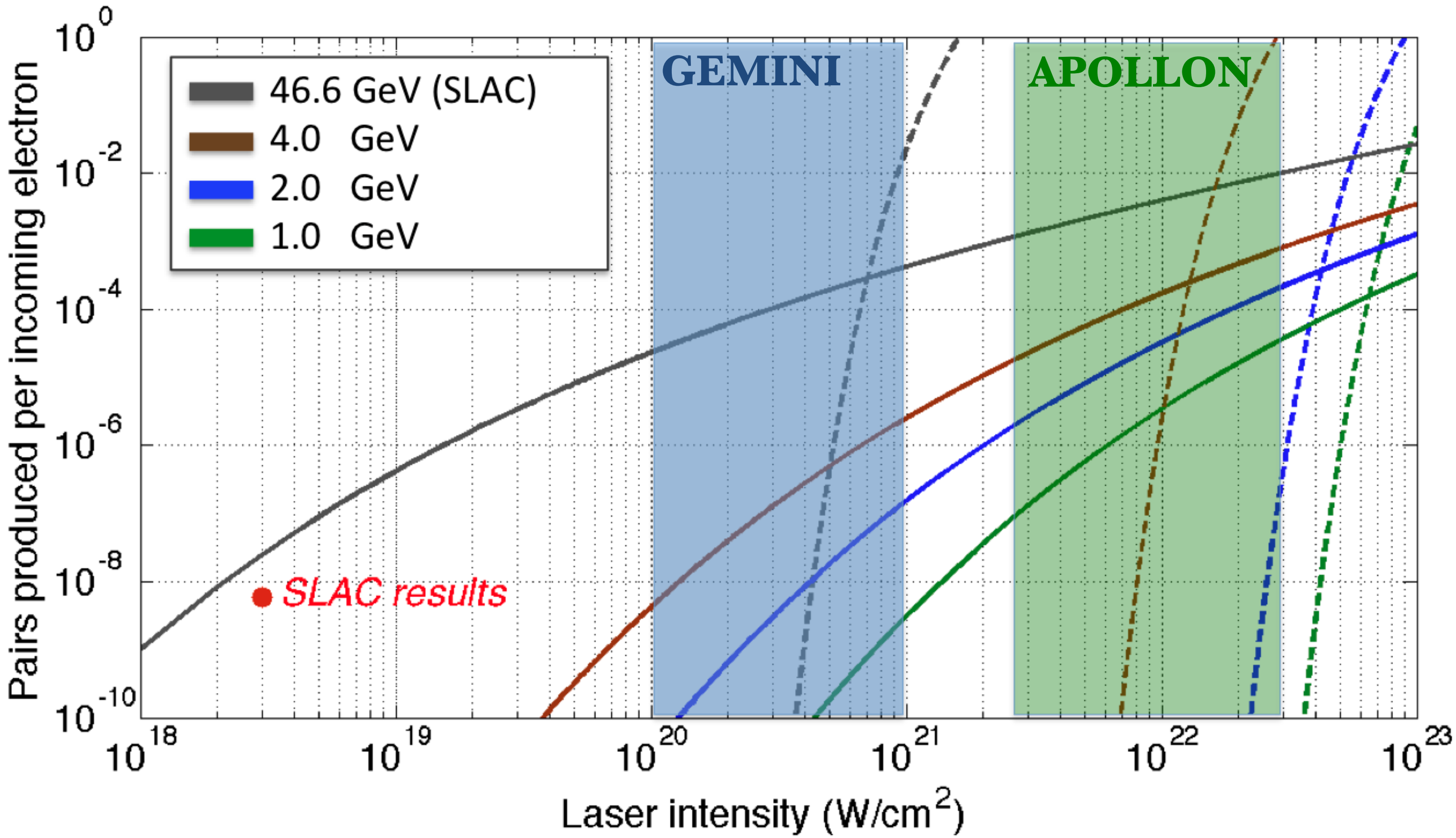


T. Blackburn et al. Phys. Rev. Lett. 112, 015001 (2014)



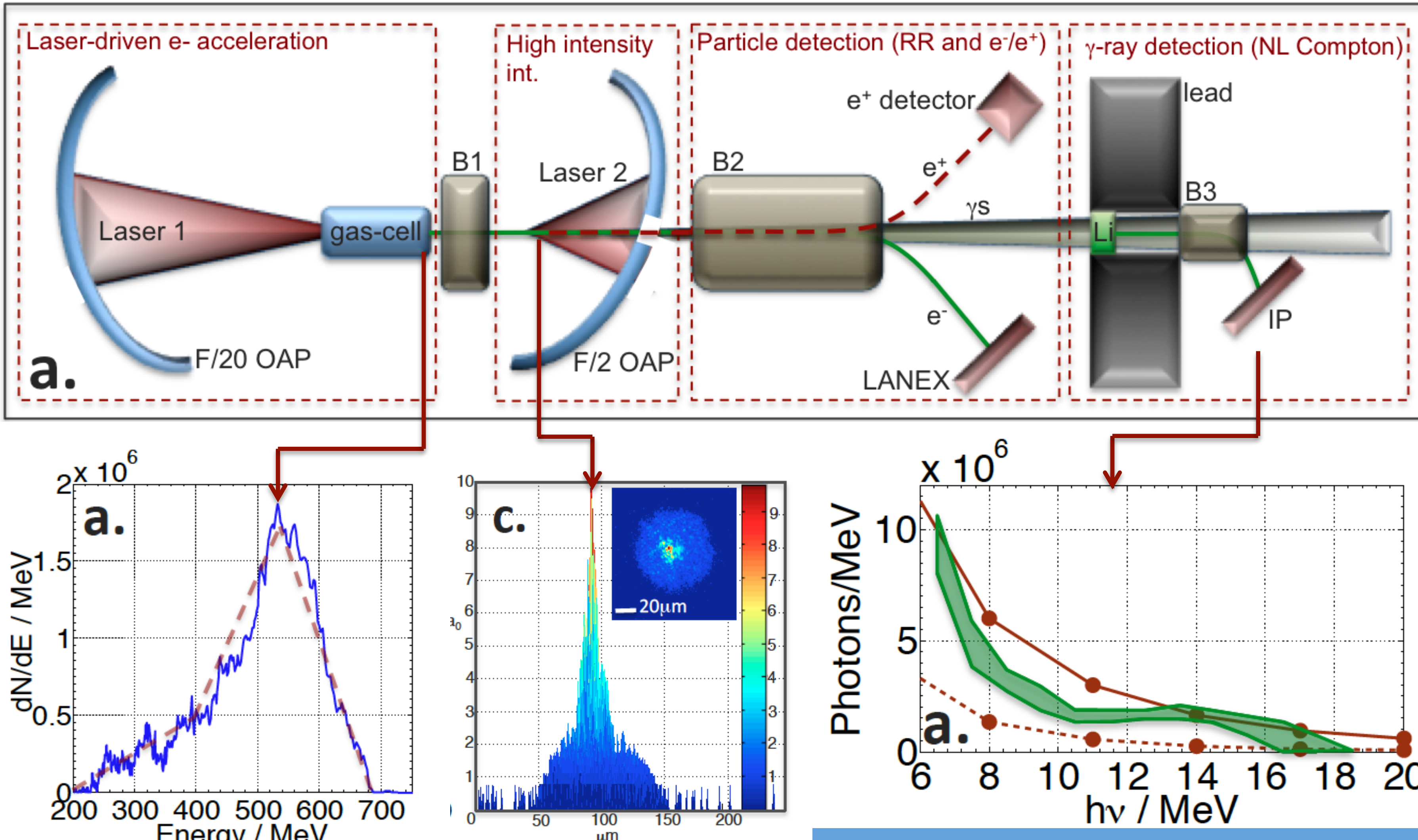
- **Possibility of appreciating stochastic photon emission**
- **Simultaneous signatures in the electron spectrum and photon beam properties**

Photon-photon cross section



- Up to 10^{-2} positrons per incoming electron at 4 GeV
- Possibility to access direct electro-production

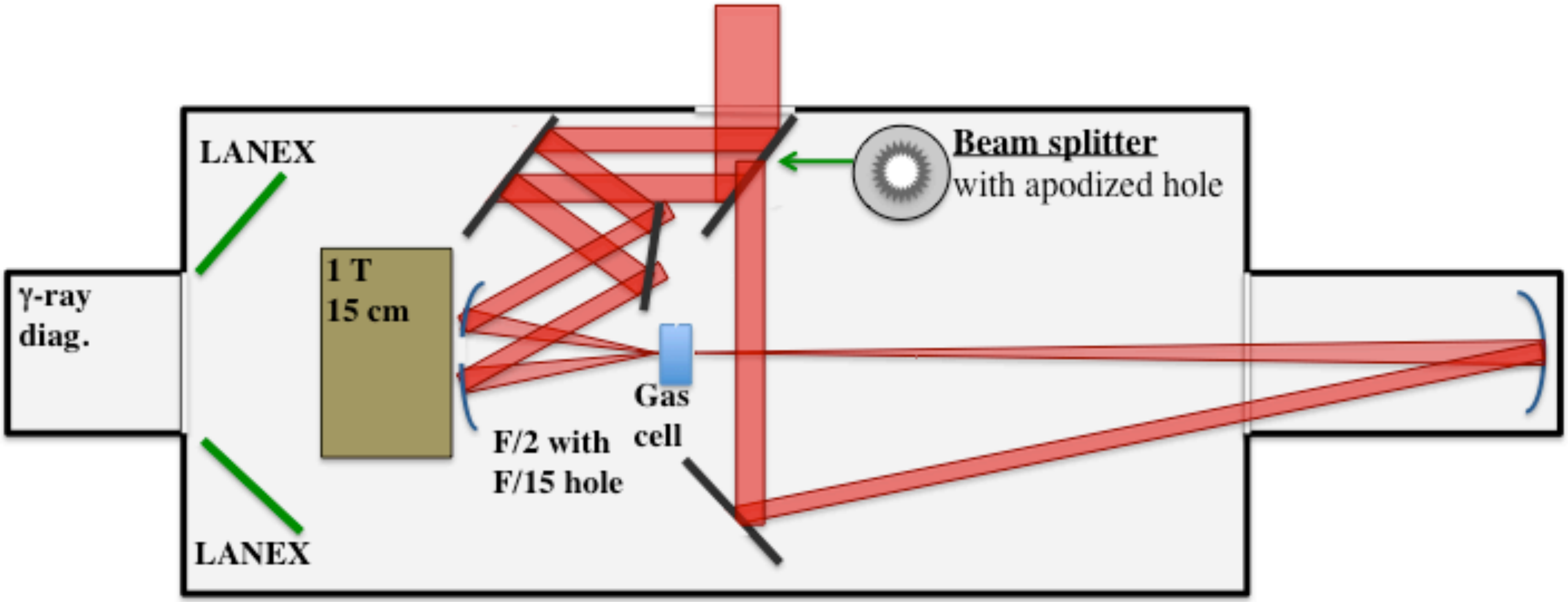
General Setup



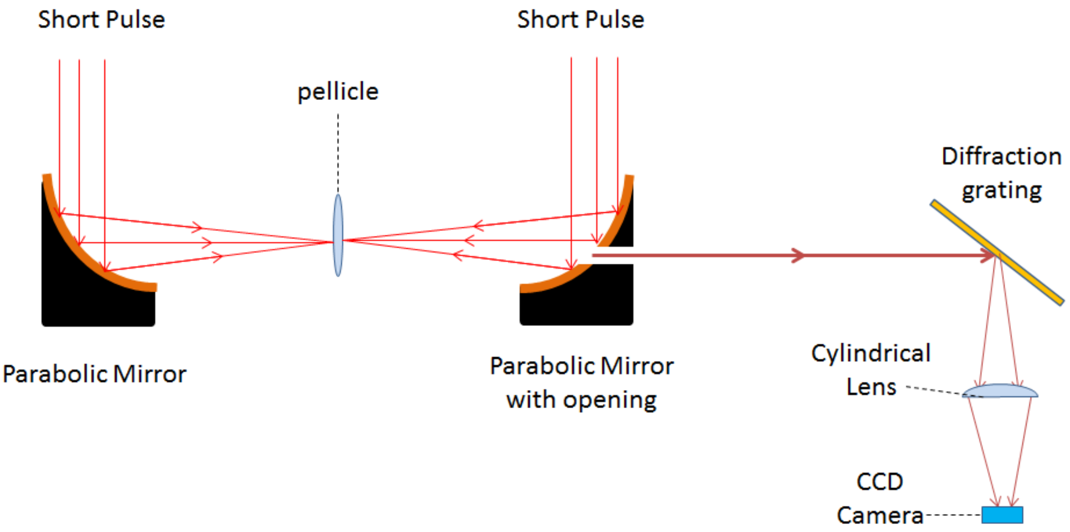
G. Sarri et al. Phys. Rev. Lett. 113, 224801 (2014)

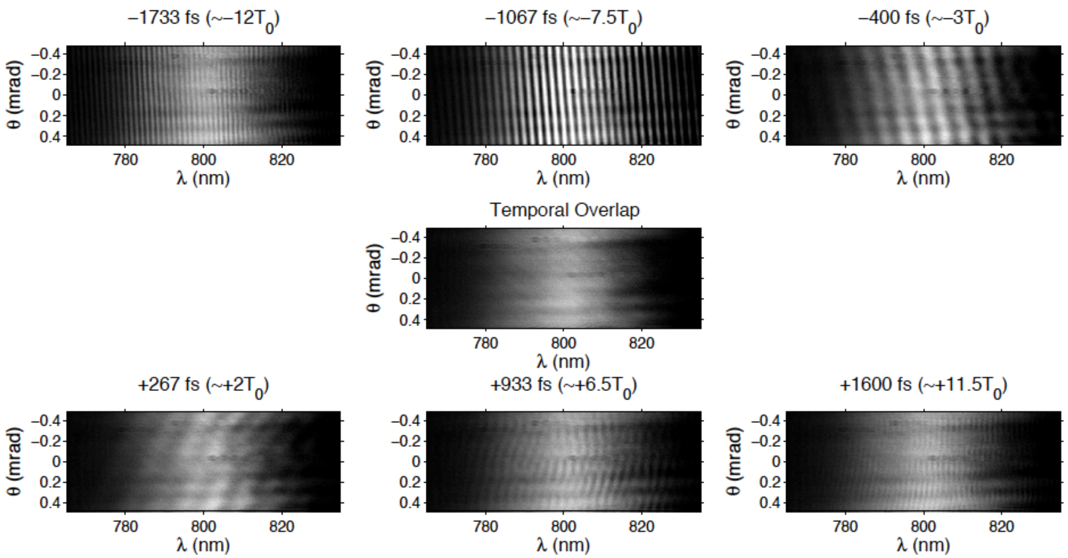
General Setup

- **SINGLE BEAM POSSIBLE SETUP**



Temporal Synchronisation

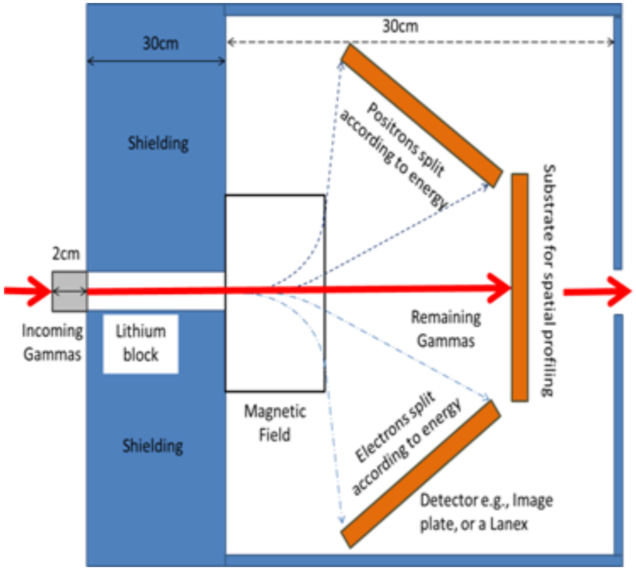


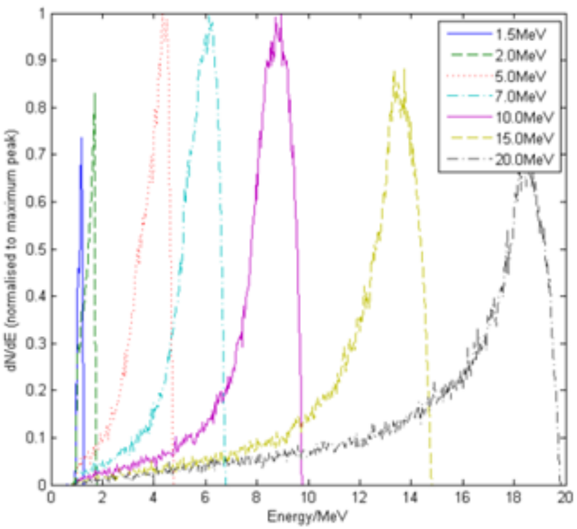


- Both laser beams are sent through the hole of the short focal length parabola onto a diffraction grating.
- Spectral dispersion along one axis provides temporal information, whilst the undispersed axis provides information on the spatial overlap.
- Temporal resolution of the order of 50fs
- Spatial resolution of the order of a few microns

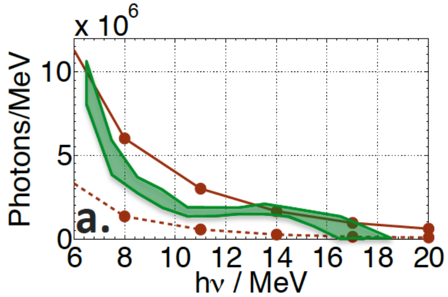
D. J. Corvan et al. Opt. Exp. 24,1852 (2016)

γ-ray spectroscopy: Li



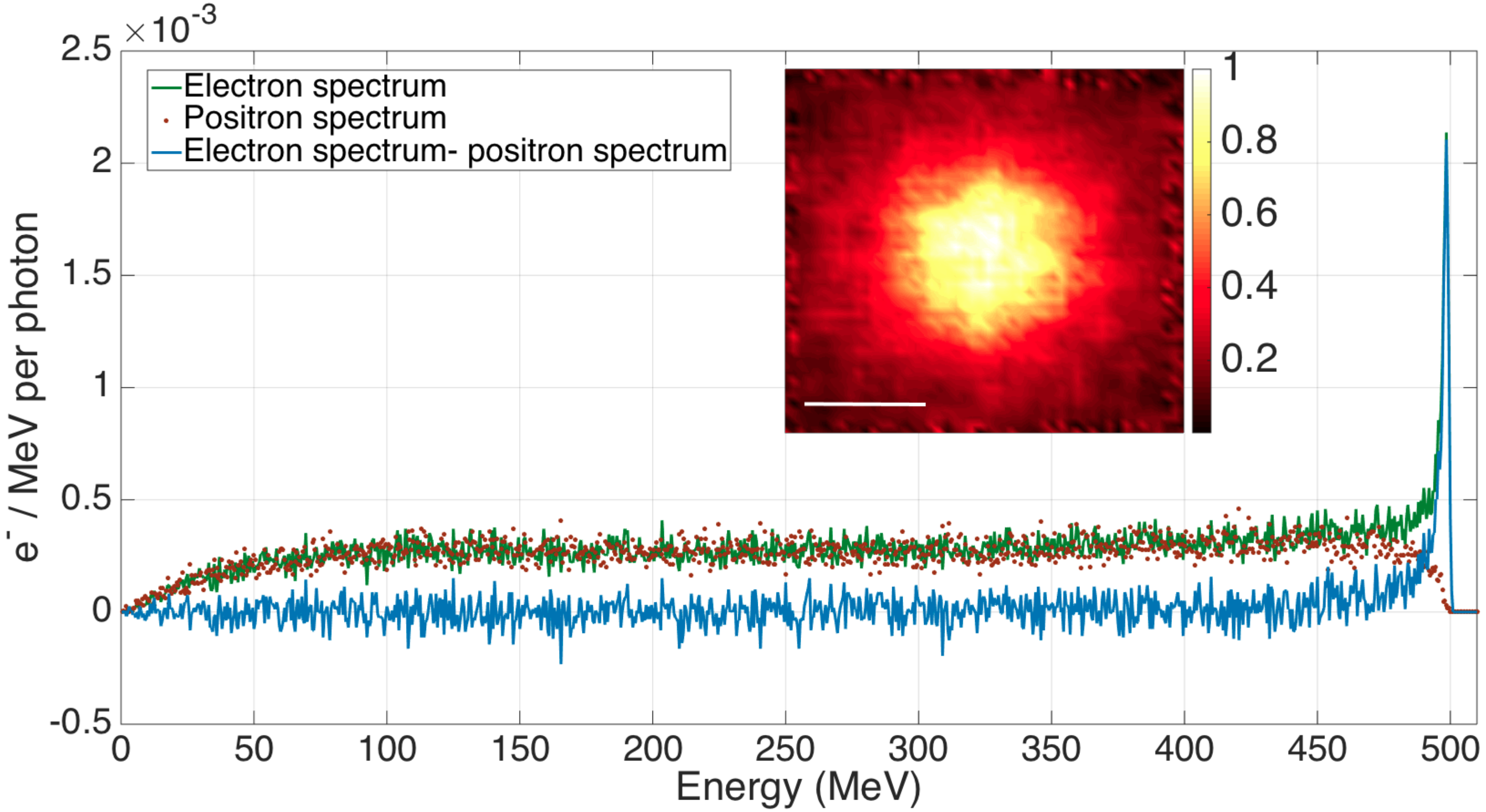


- In its basic configuration, γ-rays undergo inverse Compton scattering, generating a population of electrons with similar spectral distribution on axis.
- Electrons are then spectrally resolved and the resulting spectrum is deconvolved to give the initial γ-ray spectrum
- Energy resolution ~ 1 MeV
- Energy window 3 – 30 MeV
- Conversion into electrons ~3%



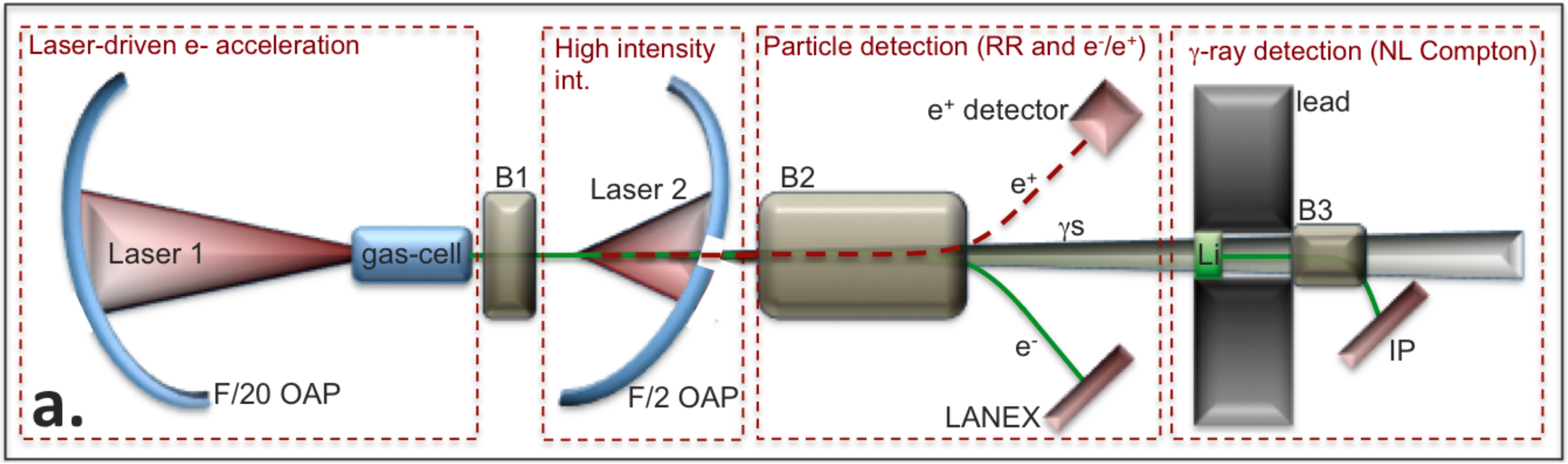
D. J. Corvan et al. Rev. Sci. Instrum. 85, 065119 (2014)

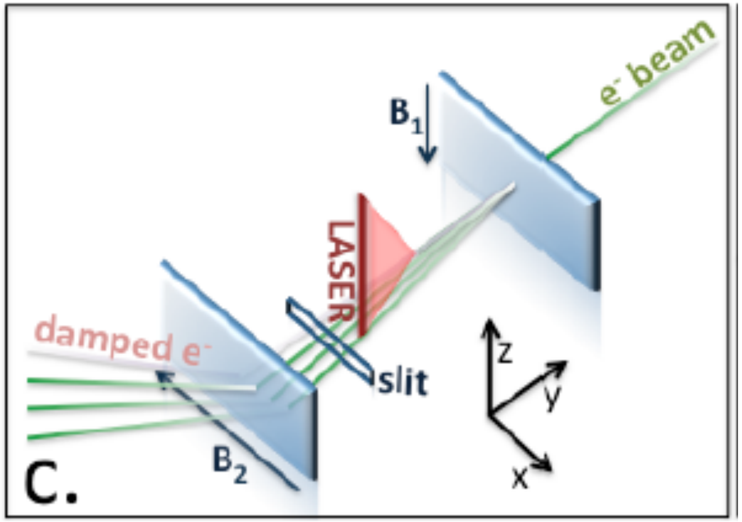
γ-ray spectroscopy: H_2

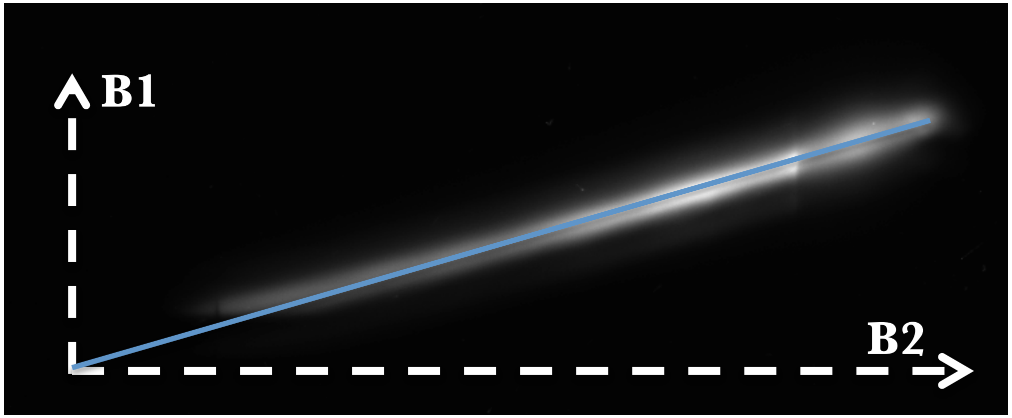


- 20 bar, 50cm long H_2 pipe
- MeV resolution up to the GeV range
- Conversion efficiency: 0.25%
- First prototype built and tested

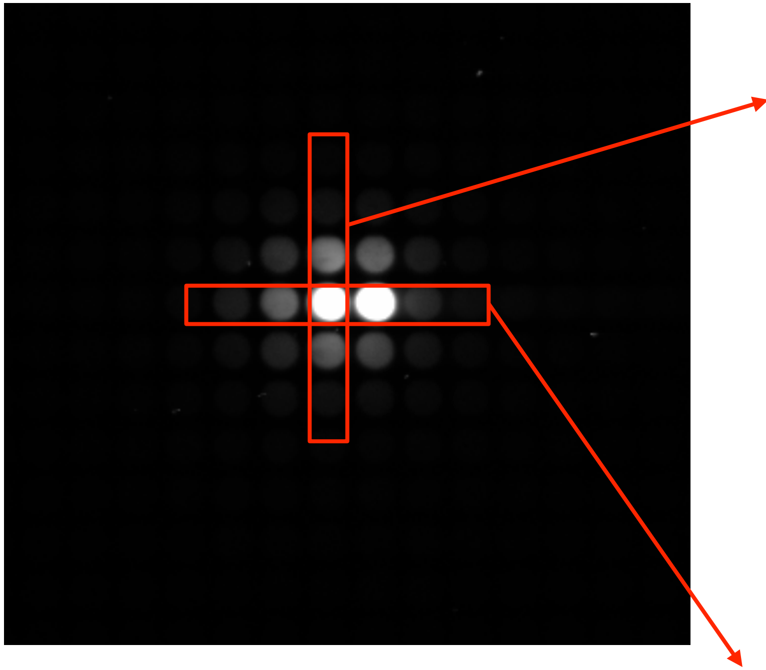
Double magnetic spectrometer

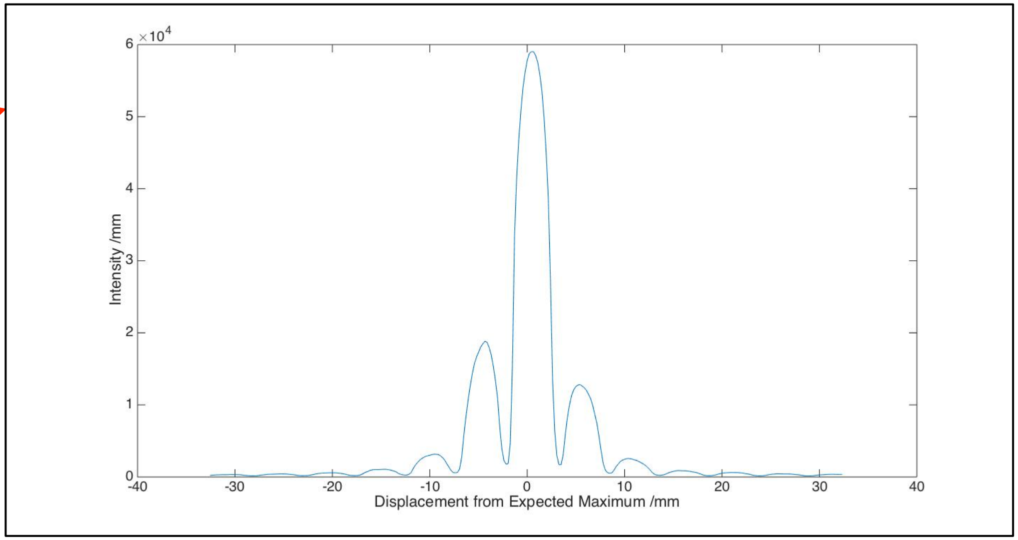


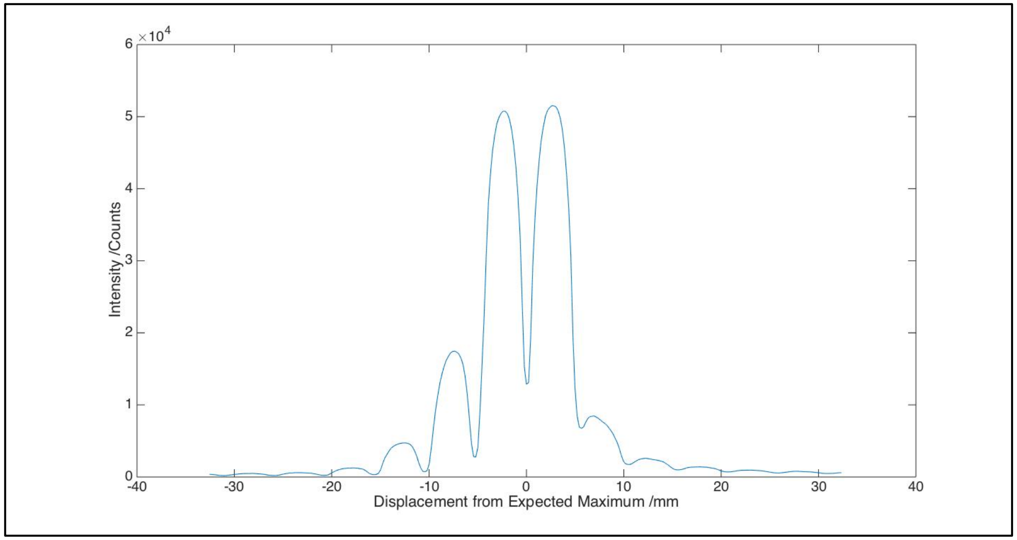




Pixelated scintillators







- **Possibility of directly measuring the laser a_0**

Conclusions

- **Unprecedented** possibility of studying physical phenomena that have been thus far out of reach of experiments

- **Radiation Reaction** experiments that can access highly non-linear and quantum regimes. First systematic and direct studies of non-linear quantum electrodynamics

- **Prolific Pair Production** in both Trident and Two-step process, with the possibility of studying the transition between the two. Possibility of directly measuring the photon-photon cross section and its non-linear corrections

- **Next generation of γ-ray beams** with unprecedented short duration, high flux, and high brilliance even in the initial stage of Apollon. Of paramount importance for progressing our knowledge in diverse fields of science.

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Thank you for your attention

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Quantum Radiation Reaction

⇒ Radiation Reaction is one of the oldest and most fundamental problems in electromagnetism: How do we correctly model the electron dynamics if we include radiative losses?

0. Classical Lorentz force

$$m\frac{du^{u}}{ds} = eF^{uv}u_{v}$$

X No energy loss

1. LAD Equation

$$m\frac{du^{u}}{ds} = eF^{uv}u_{v} + \frac{2}{3}e^{2}\left(\frac{d^{2}u^{u}}{ds^{2}} + \frac{du^{v}}{ds}\frac{du^{v}}{ds}u^{u}\right)$$

✓ Damping force (radiation reaction term)
X Classical renormalisation (point-like electron)
X Runaway solutions! (diverging acceleration even without external field)

2. LL Equation

$$m\frac{du^{u}}{ds} = eF^{uv}u_{v} + \frac{2}{3}e^{2}\left(\frac{e}{m}(\partial_{\alpha}F^{uv})u^{\alpha}u_{v} - \frac{e^{2}}{m^{2}}F^{uv}F_{\alpha v}u^{\alpha} + \frac{e^{2}}{m^{2}}(F^{\alpha v}u_{v})(F_{\alpha\lambda}u^{\lambda})u^{u}\right)$$

✓ No runaway solutions
✓ Valid in classical relativity